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CERTIFICATE

This is to certify that the attached English language document, identified as "OPTICAL MODULE", is a true and accurate translation of the original Japanese language document to the best of our knowledge and belief.

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TITLE OF THE INVENTION

Optical module

BACKGROUND OF THE INVENTION

1. Field of invention

This invention concerns an optical amplifier, which is used in an optical communication system that transmits a signal of frequency division multiplexing (FDM).

2. Related art

A video distribution system, which transmits optical signals that are frequency-division-multiplexed digital or analogue signals and distributes multi-channels of video signals to plurality of subscribers distributed with the star coupler, has been put to practical use now.

In this system, there is necessity to compensate the optical branching loss because the loss of power occurs in distribution and transmission, erbium doped optical fiber amplifier (EDFA) is widely applied to compensate it.

For the application of erbium doped optical fiber amplifier (EDFA) to the image video distribution system for the subscribers, details are described in IEEE/JLT, vol. 11, no. 1, and pp. 128-137, 1993, E. Yoneda and et al.

In general, two meanss of which is a direct modulation that directly modulated electric signals to semiconductor lasers etc. that are signal light sources, and an external modulation that controls intensity of optical signals launching form a light source with constant optical output by impressing electric signals to external modulator, are known as meanss of generating optical signals.

The system using direct modulation means can be composed comparatively cheaply.

However, the problem that the oscillation wavelength becomes a little unstable, which is called Chirp in general, occurs by modulating the semiconductor laser

itself.

Therefore, it is necessary to solve this problem of Chirp to apply the direct modulation means to high-speed modulation.

On the other hand, the external modulation excels in Chirp characteristic and is possible to apply to high-speed modulation.

At the same time, Since it is necessary to set up an external modulator outside of the laser source, there is a problem on the cost.

It is general to use the direct modulation means as a signal light source for the advantage to exist in the cost under the present situation from such viewpoints.

In such an optical communication system, Range of ±10nm in center wavelength occurs under the specification of the light source used as a signal light source by a problem of manufacturing.

Though a light source, which has a range of about ±5nm in center wavelength, actually can be prepared, the center wavelength might shift to about ±10nm that is the above-mentioned specification because there is a difference.

In this case, it is convenient for system that erbium doped fiber amplifiers (EDFA), which are the transmission devices, have wide tolerance to wavelength.

Moreover, it is advantageous on the cost that erbium doped fiber amplifiers have wide range in wavelength because wavelength of semiconductor laser need not be selected.

In addition, a transmission means, which wavelength-division-multiplexes signals that are frequency-division-multiplexed, is designed; in this case, wide wavelength range is also desired.

However, a problem, which applicable wavelength range of signal light is restricted because signal distortion is easily generated by interaction with wavelength dependent gain (gain-slope) due to big Chirp of signal light, occurs in the case of using signal light source of direct modulation means.

This point is indicated in K. Kikushima, IEEE/PTL, vol. 3, no. 10, pp. 945-947, 1991.

This signal distortion can be expressed by the second order distortion (Composite second-order distortion: CSO).

The relations among this second distortion (CSO), the gain-slope of erbium doped optical fiber amplifier (EDFA), and Chirp of the signal light can be shown by following expression (1).

The number of uniting waves of the same channel of the second order distortion is assumed to be K, the gain of the erbium doped optical fiber amplifier (EDFA) is assumed to be G, the wavelength of signal is assumed to be λ, the signal wavelength of light source is assumed to be $\lambda 0$, and the wavelength bandwidth of Chirp per channel is assumed to be λchirp, CSO is shown in expression (1), it is understood that the smaller gain-slope $dG/d\lambda$ is, the less the signal distortion is.

$$CSO = 20\log\left\{K \cdot \frac{1}{G} \cdot \frac{dG}{d\lambda}\ \Big|_{\lambda=\lambda 0} \cdot \lambda_{chirp}\right\} \text{[dB]} \qquad \text{expression(1)}$$

When the amount of the distortion which can be usually allowed in an analog system is converted into the gain-slope, it is necessary that the total of the gain-slope of all amplifiers which exist in the transmission line is about ±0.6dB/nm or less (0.6dB/nm or less in the absolute value) though it depends on the amount of Chirp of the signal light source.

Therefore, when the amplifiers of two stages are connected as shown in Figure 7 for instance, the amount of the gain-slope allowed per one amplifier is about ±0.3dB/nm or less (0.3dB/nm or less in the absolute value).

Thus, there is a means of applying erbium doped optical fiber (EDF) to which aluminum (Al) is in a high density doped to the amplification medium of erbium doped optical fiber amplifier (EDFA) as one of the control means, though it is necessary to control the gain-slope of erbium doped optical fiber amplifier (EDFA) to control the signal distortion.

This is a use of the known characteristic that the wavelength dependency of

the amplification characteristic (gain-slope) decreases when aluminum (Al) is doped in a high density to the erbium doped optical fiber (EDF).

As one example, the wavelength characteristic of the gain-slope of which using conventional equipment configuration is shown in Figure 8 when erbium doped optical fiber (EDF) wherein aluminum (Al) is doped in a high density is applied to erbium doped optical fiber amplifier (EDFA) to suppress small the gain-slope of erbium doped optical fiber amplifier.

This figure is a result of evaluating the gain-slope of erbium doped optical fiber amplifier (EDFA) when input signal wavelength and input signal optical power of the FDM signal (No WDM signal) of 1ch input to an analog amplifier are changed respectively.

The vertical axis in the graph is gain-slope (dB/nm), and a horizontal axis is wavelength (nm).

It is necessary to be careful that the gain characteristic of erbium doped optical fiber amplifier has wavelength dependency, which is not constant always but change by the input signal optical power that is input to the amplifier.

Therefore, the warrantable range in operation of erbium doped optical amplifier in an analogue optical transmission system is limited to the range within the value wherein the gain-slope is permitted in the system among the amplification characteristics which change depending on input signal optical power and the input wavelength condition to erbium doped optical fiber amplifier (EDFA).

Actually, the range where the amount of the gain-slope of 0.3dB/nm or less is selected not to generate the signal distortion due to amplification of analog signal under the condition of which is obtained by input signal power and wavelength those are possible for EDFA to amplify.

The gain-slope changes from about +0.4dB/nm to -0.9dB/nm as shown in Figure 8 when assuming the input dynamic range of 10dB in this system.

However, when this amplifier is applied to the analogue transmission system as the above-mentioned, it is not possible to use it in all these input range.

Only 5nm range of 1554-1559nm can be used in this amplifier because the range of 0.3dB/nm in the absolute value can be applied when the model of the system of two stages amplification is considered.

Therefore, if erbium doped optical fiber (EDF), which is doped aluminum (Al) in a high density, is applied, it is possible to make the gain-slope minimum in a certain condition of input signal optical power or the input wavelength.

However, it is principally impossible in all input signal optical power and the input wavelength condition to suppress the gain-slope in the level that is as low as suitable for practical use.

On the other hand, for the purpose of reducing a wavelength dependency of a gain (gain profile), there are similar optical filters such as gain flattening filters (GFF) in order to achieve a gain flattening characteristic of the WDM amplifier.

Those filters are designed the wavelength profile of transmittance to equalize the gain of each wavelength of wavelength division multiplexing (WDM) signal, such as Fiber Brag Grating (FBG) and the dielectric multi-layer film filter are used.

It is allowed even if there is some ripples in an amplitude of a loss characteristic for gain flattening filter (GFF), because the desired profile is almost a reverse-characteristic of the wavelength division multiplexing gain characteristic (The unit: dB) and it only has to satisfy the required flatness from the system side.

Therefore, such filters are not suitable for this application since it ends up that distortion has been generated unnecessarily when there is steep gain slope due to ripple and excessive negative-slope in it.

Therefore, the purpose of this invention is enabling the communication in wide wavelength band by solving above-mentioned existing problem in the optical communication system to which applies an optical amplifier and suppressing the gain-slope.

SUMMARY OF THE INVENTION

The inventors diligently researched to solve above-mentioned problem. In consequent, an optical module that was difficult in prior arts of optical transmission system to which applied an optical amplifier, that suppresses gain-slope and enables drastic expansion of available wavelength band was found as described below.

In this invention, regardless of the condition of an input signal power and an input signal wavelength, it becomes possible that a gain-slope is greatly suppressed compared with conventional one due to an optical module which combined optical amplifier, such as erbium doped optical fiber amplifier (EDFA) and a gain-slope compensation filter (GSCF).

As a result, an operation area (application area) of an amplifier is expanded, and a practical wavelength band, which is available to a telecommunication system, can be expanded.

Furthermore, an optical module of this invention is available no only to an optical distribution system but also to an optical output system and an optical input system, it is an optical module that can be applied to a variety of kinds of optical communication systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1(Fig. 1) is a figure wherein the instruments of the probe method evaluation system is shown.

Figure 2(a) (Fig. 2 (a)) is a figure wherein the device structure of an optical module of this invention is shown.

Figure 2(b) (Fig. 2 (b)) is a figure wherein a gain-slope wavelength characteristic of an optical module of this invention is shown.

Figure 3(a) (Fig. 3 (a)) is a figure wherein an equipment structure of a conventional optical amplification device is shown.

Figure 3(b) (Fig. 3 (b)) is a figure wherein a gain-slope wavelength

characteristic of a conventional optical amplifier is shown.

Figure 4 is a figure wherein gain-slope reverse-characteristic (Loss slope) calculated by the probe method is shown.

Figure 5 is a figure wherein one example of loss profile (Loss profile) of a gain-slope compensation optical filter (GSCF) is shown.

Figure 6 is a figure wherein an equipment arrangement of an optical communication system (embodiment 2), which amplifies in three stages, which apply an optical module of this invention, is shown.

Figure 7 is a figure wherein an equipment arrangement of an embodiment (three stage amplification) of an optical communication system, which applies an optical module of embodiment 1, is shown.

Figure 8 is a figure of prior art wherein the wavelength characteristic of the gain-slope of erbium doped optical fiber amplifier (EDFA), which uses erbium doped optical fiber (EDF), which is doped aluminum (Al) in a high density, is shown.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiment of the invention is explained in detail with the drawings as follows.

Though an optical module using erbium doped optical fiber amplifier (EDFA) is taken up, an amplification medium is not restricted only EDF, and amplification band is not restricted only C-band.

An optical amplifier, which amplifies a signal light by an excitation structure like an EDFA; for instance, Tellurite, Fluoride, or Silica, etc. for the host glass, the Thulium, Praseogeum, Ytterbium, Terbium, or Neodymium, etc. for dopant as amplification medium, can be applied.

In addition, all kinds of optical amplifiers such as the semiconductor amplifiers can be applied.

This embodiment is an optical module, which combines erbium doped optical fiber amplifier (EDFA) with gain-slope compensation optical filters (GSCF).

It is possible to suppress small a gain-slope of an erbium doped optical fiber amplifier (EDFA) by using this optical module.

Therefore, it is possible to expand an operation area (application area) of an analogue amplifier by applying a gain-slope compensation optical filter (GSCF).

Here, gain-slope compensation optical filter (GSCF) is designed by the following methods.

(1) Measurement of gain-slope

In the case of inputting a signal light with Chirp to erbium doped optical fiber amplifier (EDFA), an inversion population of erbium doped optical fiber amplifier is decided according to the average wavelength of signal light without being influenced by Chirp because the response speed of erbium doped optical fiber amplifier (EDFA) is about ms.

On the other hand, the signal light is influenced by gain wavelength dependency (gain-slope) due to the extension of wavelength due to Chirp.

Therefore, by utilizing this, the gain-slope can be measured with the evaluation system shown in Figure 1.

> Gain-slope evaluation method (probe method)

The signal of wavelength equal to the signal to transmit the analogue signal is assumed to be Locked Inversion Signal.

Against this, low signal optical power, which does not influence an amplification characteristic of an amplifier, is assumed to be Probe Signal.

It is preferable that the difference of the power level of Locked Inversion Signal and Probe Signal is about 20dB or more.

These two signals are combined by Star Coupler and used as an input signal of an amplifier.

Locked Inversion Signal is set to prescribed wavelength because it is the signal which is actually applied frequency-division-multiplexed (FDM) carrier signals on.

Probe Signal is assumed to be swept at intervals of ± several nm centering

on Locked Inversion Signal since it is a signal which evaluates LI (Locked Inversion) Gain of its neighborhood.

The input signal combined Locked Inversion Signal and Probe Signal, which is previously explained, is input to an erbium doped optical fiber amplifier (EDFA)

Wavelength dependent LI Gain generated on condition of population inversion, which is formed by sweeping this Probe Signal and inputting Locked Inversion Signal, is calculated by using expression (2) from Probe Signal.

$$LI\ Gain(\lambda) = \frac{Pout, prb(\lambda) - Pase, prb(\lambda)}{Pin, prb(\lambda)} \quad [\mathrm{dB}] \qquad \text{expression (2)}$$

Here,

LI Gain(λ): LI Gain in each wavelength (dB)

Pin, prb(λ): Input Probe signal power in each wavelength (dB)

Pout, prb(λ): Output Probe signal power in each wavelength (dB)

Pase, prb(λ): ASE(Amplified Spontaneous Emission) power of probe light in each wavelength (dB)

(2) Calculation of gain-slope reverse-characteristic

Next, wavelength dependent LI Gain (λ) that centers on prescribed wavelength is approximated in the second order function and reverse-characteristic of gain-slope (unit: dB/nm) of input signal wavelength calculated by first order differentiation is solved.

Loss slope, which is reverse-characteristic of gain-slope such as showing the example in Figure 4, is obtained by executing the calculation of the gain-slope in each wavelength.

Here, the vertical axis in the graph shows loss slope (dB/nm), and the horizontal axis shows wavelength (nm).

Because this loss slope (Loss slope) compensates the gain-slope (Gain-slope) of erbium doped optical fiber amplifier (EDFA), the profile

of gain-slope compensation optical filter (GSCF), which reflects this result, is decided.

As a reference, one example of loss profile (Loss Profile) of gain-slope compensation optical filter (GSCF) is shown in Figure 5.

Here, the vertical axis in the graph shows loss profile (dB), and the horizontal axis shows wavelength (nm).

Moreover, though this probe method is the most general as method of evaluating the gain-slope, and the most excellent method of obtaining an accurate value, it is also possible to use other methods.

Moreover, though the calculation of reverse-characteristic of the gain-slope is calculated by the first order differentiation of the quadratic function approximation in this invention, other function etc., which can approximate accurately an arbitrary gain-slope, may be used.

In this invention, an erbium doped optical fiber amplifier (EDFA) wherein a signal distortion is suppressed in a wider wavelength band can be obtained by analyzing a wavelength characteristic of the gain-slope to generate second order distortion (CSO), designing an optical filter which has a reverse-characteristic of a gain-slope to compensate for it and using this optical filter.

Therefore, if it satisfies described above, it is possible to take unprescribed methods other than above-mentioned methods or functions.

<u>EXAMPLE</u>

Example 1

An example of arrangement which is applied the gain-slope compensation optical filter (GSCF) designed by the above-mentioned method to an erbium doped optical fiber amplifier (EDFA) is shown in Figure 2(a), and the wavelength characteristic of the gain-slope in this case is shown in Figure 2(b), respectively.

This example is showing a case of installing a gain-slope compensation optical filter (GSCF) to the position of interstage where it is possible to be utilized

most effectively.

However, even if a gain-slope compensation optical filter (GSCF) is installed on an input end or an output end of an amplifier, the effect for the distortion can be obtained.

Nevertheless, deterioration in noise figure (NF) of the amplifier is caused when the gain-slope compensation optical filter (GSCF) is connected with the input end, also, it is worried that the effect such as decreases of output efficiency of the amplifier when it is connected with the output end.

When the gain-slope compensation optical filter (GSCF) is actually applied to such an optical transmission system, the above-mentioned factor should be considered too.

Here, as the prior art, the example of the optical amplification device with no gain-slope compensation optical filter (GSCF) is shown in Figure 3(a), and the wavelength characteristic of the gain-slope in this case is shown in Figure 3(b), respectively.

Similar to the above-mentioned fact, the applicable range of gain-slope in one amplifier is 0.3dB/nm when considering the optical communication system of two-stage amplification.

Here, the gain-slope wavelength characteristic of this invention is compared with the gain-slope wavelength characteristic of the conventional model.

As shown in Figure 3(b), although the applicable wavelength range is no more than 5nm in the conventional arrangement, it is possible to confirm an excellent operation in the wavelength range of 20nm, about four times of the conventional one, with the arrangement of this invention shown in Figure 2(b).

Therefore, it was proven that this invention has an advantage which increases applicable wavelength range greatly.

The schematic of the optical communication system, which applies an optical module of this invention, is shown in Figure 7.

If an optical module of this invention shown in Figure 2(a) is installed in the

interior of any of each amplifier (EDFA1-EDFA3) or all, the arrangement of the optical communication system, which applies the module of this example 1, will be shown.

Moreover, though an example of the tandem connection of three stage amplifiers are shown in this example, this is only one example, and if the total of the gain-slope of the amplifier is within a required value of the system, either of 1-n (n is an integer) is acceptable as number of stage of amplifiers.

Example 2

It is not that an effect is not acquired, as long as the gain-slope compensation optical filter (GSCF) of this invention is not installed for every optical amplifier.

As embodiment 2 shown in Figure 6, it is possible to compensate the gain-slope by installing gain-slope compensation optical filter (GSCF) to an arbitrary place between transmitter and receiver, not installing gain-slope compensation optical filter (GSCF) to each amplifier, for the signal light that is transmitted through plurality of EDFA.

In this example, when the gain-slope characteristic of a plurality of erbium doped optical fiber amplifiers (EDFA) are almost the same or the gain-slope characteristic can be expected, reverse-characteristic of gain-slope compensation optical filter (GSCF) can be obtained by these additional gain-slope characteristics.

Moreover, in the case of the gain-slope characteristics are different each other, it is possible to analyze and design the gain-slope reverse-characteristic of gain-slope compensation optical filter (GSCF) after measuring the gain-slope characteristic of a plurality of erbium doped optical fiber amplifiers (EDFA) by the method such as probe method shown previously.

Of course, it is also possible to install an optical module of this invention shown in Figure 2(a) in each amplifier, and to add gain-slope compensation optical

filter (GSCF) to the interstage of the amplifier in addition.

As mentioned above, it is possible to install the optical module of this invention, and it is also possible to construct the optical module of this invention to install the gain-slope compensation optical filter (GSCF) in the interstage between amplifiers in this invention.

In addition, it is also possible to combine optical modules of both types.

Moreover, if the total of the gain-slope of the amplifiers is within a required value of system, the number of stages of amplifiers is acceptable either of 1-n (n is an integer).

Thus, by using gain-slope compensation optical filter (GSCF) of this invention, it is possible to use a wider signal light wavelength band in the amplifiers including erbium doped optical fiber amplifier (EDFA) and the optical transmission system using it.